Designing Genetic Algorithms for Adaptive Routing Algorithms in the Internet

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1 Introduction

Rapid expansion of the Internet increases demand on reliable and efficient routing algorithms. At the beginning of this year, there were 43,230,000 hosts connected to the Internet (Source: Network Wizards (www.nw.com)) and the next generation IPv6 provides 128 bit address space, which can allocate 3.4×10^{38} addresses. (We can allocate 6.6×10^{19} addresses in $1cm^2$ on the earth!) Therefore, routing algorithms in the Internet must be scalable. For a routing algorithm to be scalable, we cannot take a centralized approach in which one or a limited number of nodes control the whole routing process in the network. Instead, routing protocols in the Internet employ distributed algorithms which decide routes in each node independently. For example, the Routing Information Protocol (RIP) is based on Bellman-Ford's distributed algorithm which broadcasts routing tables to calculate distances and directions toward shortest paths.

In the application of GAs to network routing algorithms, much work has already been done for static route allocation problems based on a centralized approach. They are simply classified into combinatorial optimization problems and are amenable to GAs. To realize adaptive routing algorithms, however, there exist fundamental difficulties as follows:

- Communication latency causes uncertainty in observation of the network status.
- Overheads of the routing information exchange affects network status itself.

Communication latency makes it difficult to obtain correct network status especially when it changes rapidly. Adaptive algorithms need to send packets frequently to observe network status, which degrades overall performance of the network. When we employ a broadcast to distribute routing information, its communication cost becomes at least $O(n^2)$, where n is the number of nodes in a network. Therefore, it is difficult for routing algorithms to be adaptive and at the same time scalable. Current routing protocols in the Internet such as the RIP and the Open Shortest Path First protocol (OSPF) do not observe communication latency of routes: they employ static distance such as hop count metric.

Evolutionary algorithms such as GAs are expected to be a promising answer to such difficult adaptation problem because of the following reasons:

- Evolution is essentially a distributed process in which each creature acts independently to adapt to its surrounding environment.
- Adaptation by the evolutionary process is achieved with relatively small communication overheads. For example, there is no direct information flow among chromosomes and creatures do not communicate so frequently during their adaptation process.
- Evolution process is considered robust to environmental change.

Our final goal is constructing an adaptive distributed routing algorithm that has such favorable characteristics of natural evolution process. In the following, we give a brief introduction to the genetic adaptive routing algorithm (GARA) [1, 2, 3], which is followed by some discussions on future direction of research in this area.

2 The Genetic Adaptive Routing Algorithm

We proposed the genetic adaptive routing algorithm (GARA) [1, 2, 3] to realize an adaptive routing algorithm with less communication overheads by observing communication latency of a limited number of routes generated by *path genetic operators* designed for this purpose. Figure 1 shows an overview of the GARA.

The GARA is a distributed routing algorithm which

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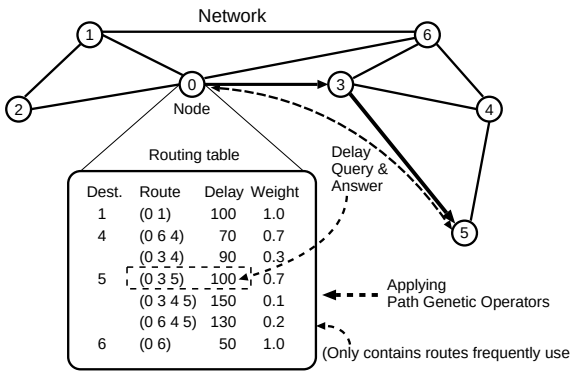

Figure 1: The Genetic Adaptive Routing Algorithm

executes the same algorithm in each node independently according to the following sequence: when a packet needs to be sent, a route is selected from alternative routes in a routing table probabilistically according to its fitness value. The fitness value of a route is evaluated by observing delay along it. After fitness evaluations, *path genetic operators* are applied at specified intervals to generate alternative routes only for destinations where packets are frequently sent. Selections are performed to reduce the size of the routing table by removing a route with largest communication latency or a set of routes to a destination where packets are sent least frequently among all the destinations.

The path genetic operators consists of *path mutation* and *path crossover* applied to route(s) encoded into a list of node IDs. To apply a path mutation, first, a node is randomly selected as a *mutation node* from nodes along a route. Second, another node is selected from neighbors of the mutation node. Finally, we mutate the route by connecting the source node and the selected node, and the selected node and destination by Dijkstra's shortest path algorithm. *Path crossover* exchanges sub-routes among a pair of routes. First, we select a node as a crossing site from nodes included in both routes. Second, crossover is performed by exchanging nodes after the crossing site. When we do not have a common node in a pair of routes, we cannot select a crossing site and we do not perform a crossover.

3 Future directions

GA design

In the GARA, we employ path genetic operators such as path mutation and path crossover based on network topology. We have also proposed addition/deletion operators elsewhere[3] that modify routes after migrations to exchange routes among nodes, because representation of routes is location dependent, for example, all routes in node 2 must begin with "2". We may design more sophisticated genetic operators like cut/splice operators employed in the messy GA in order to preserve tight linkage, which is essential to effective mixing through crossover. Another important issue in GA design is how to evaluate fitness values. In the GARA, fitness values are obtained by normalizing observed communication latencies among alternative routes to the same destination. Another criteria may be employed such as bandwidth reliability, load status, and communication cost of links.

Implementation

It is still difficult to replace conventional routing protocols in the Internet by those based on the GARA because of its source routing approach that determines a packet's entire route in its source node. The Internet protocol (IP) has a source routing option, however, it is not frequently employed and only next hops are specified in each node in order to reduce the header size of data packets. In adaptive routing algorithms which determine routes independently, only specifying next hops may cause some serious problems such as loops, unreachable routes, oscillations, and so on. This is the reason why we employ a source routing approach in the GARA. A practical approach we consider now is designing genetic operators for routing algorithms employing a partial source routing that specifies a limited number of nodes along a route. To forward packets between the nodes, we can employ conventional next-hop based approach. In relation to this, we should seek for applications of the GARA to routing information management in exterior gateway protocols (EGP) which is employed among autonomous systems (AS). Recently, the border gateway protocol version 4 (BGP4) is usually employed, in which the source routing approach is employed that specifies complete paths consisting of ASs.

References

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